Geomorphic modeling of macro-tidal embayment with extensive tidal flats: Skagit Bay, Washington

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LONG-TERM GOAL

The long-term goal of the project is to better understand processes affecting morphologic changes of muddy tidal flats and provide quantification of these changes to tidal action, river discharge, and shoreline development (e.g., dikes and jetties).

OBJECTIVES

The objective of this effort is to demonstrate the use of a community numerical model for prediction and investigation of tidal flat morphology and forcing parameters. The Office of Naval Research (ONR)/Delft community model is being evaluated as a physically based numerical simulation tool for several investigations, and this effort applies it specifically to tidal flat/channel systems.

Within this objective, the investigators seek to investigate the relative roles of tidal action, river discharge, and shoreline modification on flow over the tidal flats and resulting effects on morphologic modeling. From a model-tuning perspective, this objective includes advancing the understanding of the sensitivity of the model to parameter value adjustments and inclusion or exclusion of specific sediment transport processes and characterization in tidal flat and channel systems.

Additionally, the investigators intend to compare model simulation results with observations. The model fidelity should be improved by incorporation of observational data for configuration, assignment of boundary and initial conditions, and for calibration and validation efforts. The benefit of using a model to help with the design of the field programs and the interpretation of observational datasets has been demonstrated in other studies (e.g., Hibler et al., 2008).

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APPROACH

A three-phase approach is being used. All phases are model-configuration and evaluation-intensive. In the first phase, the model was configured with best available information. Sensitivity tests were conducted on variations in river discharge to circulation in Skagit Bay. In the second phase (previously reported), adjustments to the model were made to intensify focus in portions of the bay where field activities occurred in 2008 and 2009. Continued incorporation of the observational datasets will enable further model improvement. In the third phase, final model evaluation and the incremental phased improvement assessment will be completed and reported upon.

This work builds upon what has been reported for numerical modeling of geomorphology using Delft3D (e.g., Lesser et al., 2004; van Duin et al., 2004, Marciano et al., 2005; Tonnon et al., 2007; van Rijn et al., 2007). The sensitivity analysis focuses on bottom type classification (e.g., sediment type) and its impact on sediment transport through bottom roughness parameter variation. Process studies on idealized channels are conducted as needed.

Both Mr. Lyle Hibler and Dr. Adam Maxwell conduct model simulations. Lyle Hibler focuses on project management, model experimental design, circulation modeling, reporting, and interaction with other program participants. Adam Maxwell focuses on carrying out numerical experiments, sediment transport and morphology, and data visualization and management.

WORK COMPLETED

Three tasks were completed during the funding period from October 2009 through December 2009 as the second phase of this project. These included transition of the three-dimensional treatment of the Skagit River to a two-dimensional vertically averaged subdomain while still maintaining a three-dimensional model in Skagit Bay. This transition dramatically reduced computational times without a notable loss of model skill. The second task involved the sharing of flow information with Arete Associates with which we hope to compare modeled flow with remotely sensed surface flows. The most significant development that occurred during this period was the inclusion of sediment transport into the model simulations. Both cohesive and noncohesive sediments were modeled. Although the cohesive sediments appear to be transported reasonably, cohesive sediment transport remains a work in progress. The status of the project was reported at the 2010 AGU Ocean Sciences Conference (Maxwell et al., 2010) and at the ONR Tidal Flats Symposium (Hibler et al., 2009).

In September 2010, third phase of the project was funded, and two activities are currently underway. Dr. David Ralston at Woods Hole Oceanographic Institution (WHOI) is conducting a modeling study on the Skagit River and Skagit Bay using FVCOM. As suggested by ONR, an effort was made to ensure a more consistent model bathymetric configuration. Dr. Ralston shared Skagit topography and bathymetry with Battelle, and incorporation of this dataset is ongoing. Battelle has overlaid the WHOI bathymetry on a registered image of the site (see Figure 1). Both the former Battelle bathymetry and the WHOI bathymetry were based on an integration of publicly available gridded datasets, Tidal Flat DRI-derived bathymetric datasets, and best guess estimates of channel geometry where this data was missing. Both Battelle and WHOI best guesses in these areas are now becoming more consistent where we have identified them to be different. This is especially notable in the location of the channels of the North and South Forks of the Skagit River. Figure 1 shows a comparison of these two datasets for a sample west-to-east running transect. Because the WHOI dataset covers a larger area than the Battelle

dataset, Battelle will adopt the WHOI dataset and adjust the Battelle model accordingly rather that advocating the reverse.

The second activity is the evaluation of the new version of the Delft3d-FLOW code, version 3.28.10. Battelle is rerunning the simulations last reported by Hibler et al. (2009) and Maxwell et al. (2010) to determine whether the new version produces results different from those previously reported by Battelle.

RESULTS

Results of the study were presented by Hibler et al. (2009) and Maxwell et al. (2010). Preliminary estimates of cohesive sediment fluxes over the tidal flat were estimated; the riverine flux of cohesive sediment fluxes was based on United States Geological Survey (USGS) data. The impact on sediment flux due to the jetty near the north fork of the Skagit River was investigated. The general validity of the northward flux of North Fork sediment is being evaluated against observations reported by the University of Washington (UW) (Dr. Nittrouer and Kristen Lee).

Sediment transport through for Section A (shown in Figure 2) was estimated for two cases: the existing conditions with the jetty (shown in blue) and a case where the jetty was removed (shown in red). The top panel shows the tidal elevation; the middle panel shows discharge through the North Fork of the Skagit River, and the bottom panel shows the estimated sediment flux. As expected, the jetty does not influence the estimated water discharge from the North Fork. However, along the bay transect, the flux of sediment is significantly different between these two cases, with the jetty enhancing the northward flux of sediment beyond its physical structure. With the jetty in place, a net northward flux of North Fork sediment is estimated occur. When the jetty is removed, a westward sediment transport path (see Transect B in Figure 2) is opened up, which deprives the northward net transport path of sediment in the bay proper (see Transect A in Figure 2). These trends are associated with only North Fork sediments and have yet to be fully verified by the UW observational assessments.

IMPACT/APPLICATIONS

The impact from this work will be further evaluation of the ONR/Delft community model for geomorphological simulation in an environment that is of interest to the Office of Naval Research and in the Navy, where the software already is being used for other applications. Sensitivity analyses produced in this study will be useful in assessing the data requirements for simulation in data-limited areas. This study has also demonstrated methods for integration and comparison of remotely sensed and in situ measured data with simulated data for assessment of model performance. The focus over the last year has been in gaining understanding on the impacts of shoreline development on sediment transport with implications to the estimation of tidal flat morphology.

RELATED PROJECTS

Concurrent modeling work is also being done to support a program titled Observations and Modeling for Source Characterization (N000140810508) with Dr. Mark Moline (California State Polytechnic University), Dr. Eric Terrill (Scripps Institution of Oceanography [SIO]) and Dr. Ap Van Dongeren (Deltares). Lyle Hibler and Maarten von Ormondt (Deltares) are using the Delft3d-FLOW to investigate

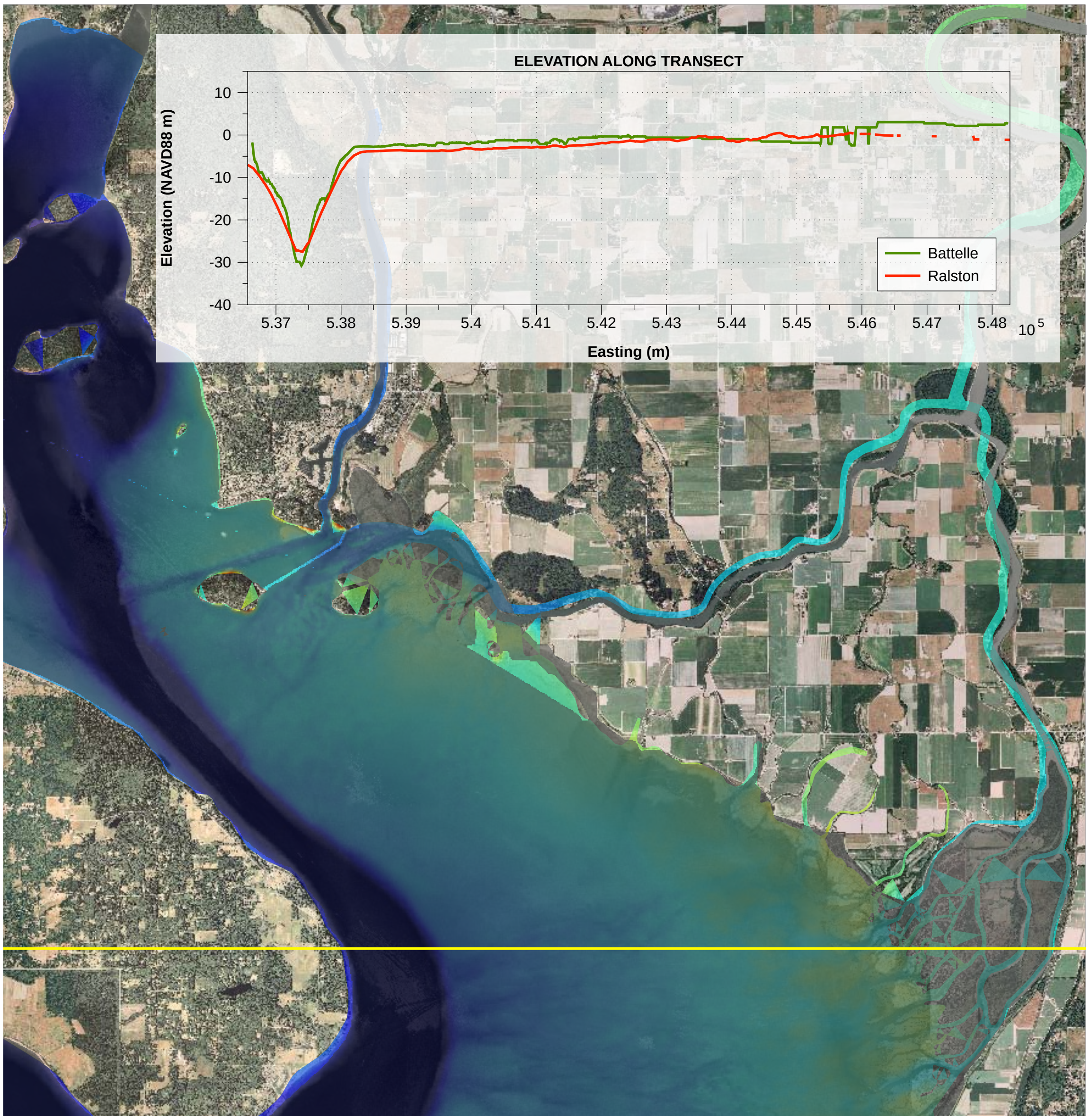

Figure 1: The WHOI bathymetry is being evaluated for its consistency with the Battelle composite dataset used to configure the Delft3d-FLOW model. The inset panel shows both the bathymetry along the west-to-east transect, shown in yellow. The west portion of the transect covers the Skagit Bay "gutter" and the east portion intersects with the South Fork of the Skagit River. The differences between these two bathymetries are likely related to the differences in interpolation or smoothing processes used to prepare the data for incorporation into model configuration with differing spatial resolutions.

Figure 2: The estimated mud flux is accounted for through two cross-sections noted as A and B. The black arrows indicate that positive flux is outward. The jetty location is also noted. The time series of sediment fluxes for A is shown in Figure 3.

the circulation with the Southern California Bight, with focus on the Tijuana River plume. Integration of larger-scale model (Southern California NCOM) and observational datasets are the focus of this effort. Battelle has recently received a ONR subaward (N000141010678) to evaluate the exchange of water over reefs, into lagoons, and through reef passes in the Republic of Palau.

PUBLICATIONS

Maxwell AR, LF Hibler, and MC Richmond. 2010. Simulation of flow and sediment transport in Skagit Bay. Presented at AGU Ocean Sciences Meeting, Portland, OR. PNWD-SA-8756.

Hibler LF, AR Maxwell, and MC Richmond. 2009. Simulation of flow and sediment transport in Skagit Bay. Presented by Lyle Hibler at ONR Tidal Flats Symposium, Boston, MA, on October 28, 2009. PNWD-SA-8773.

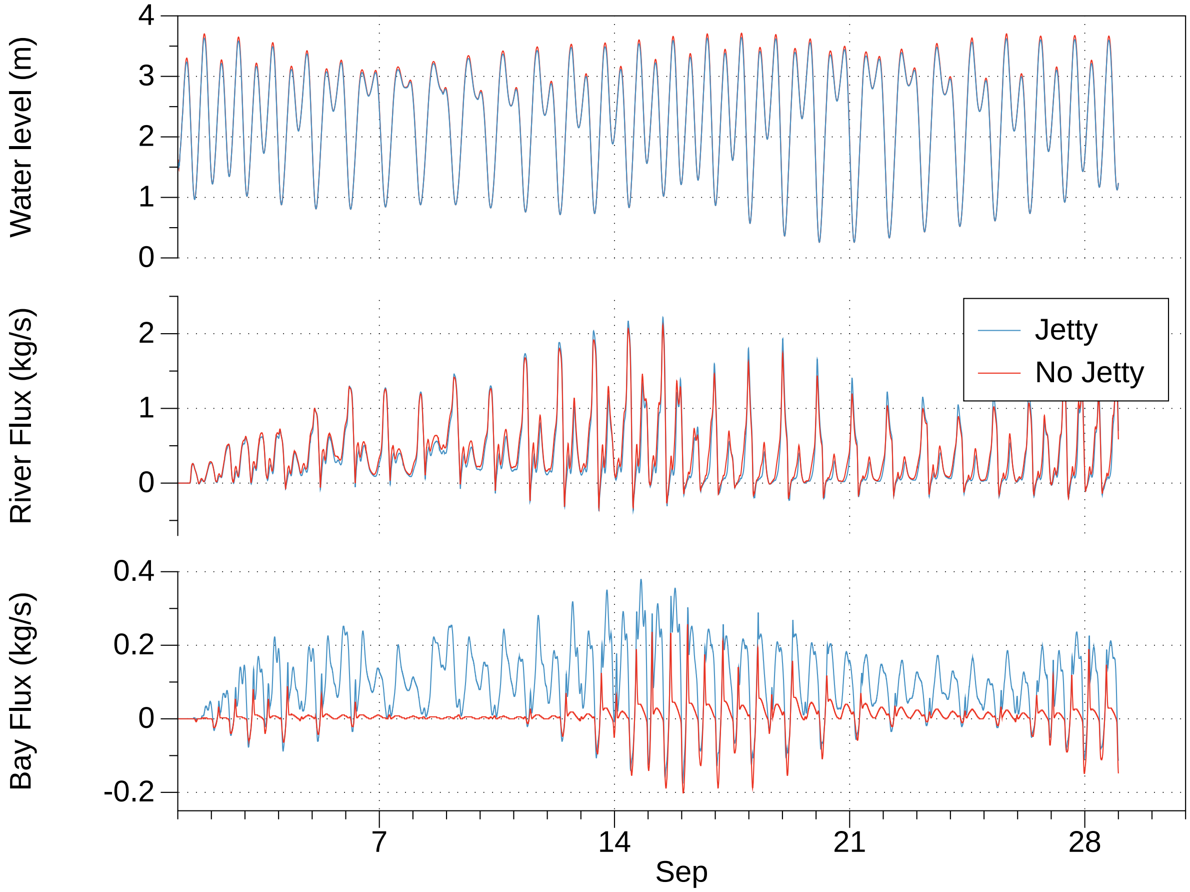

Figure 3: The model estimate for sediment transport through Section A (shown in Figure 2) was estimated for two cases: the existing conditions include the jetty (shown in blue) and a case where the jetty was removed (shown in red). The top panel shows the tidal elevation; the middle panel shows discharge through the North Fork of the Skagit River and the bottom panel shows the estimated sediment flux. As expected, the jetty does not influence the estimated water discharge from the North Fork. However, along the bay transect, the flux of sediment is significantly different between these two cases, with the jetty enhancing the northward flux of sediment beyond its physical structure.